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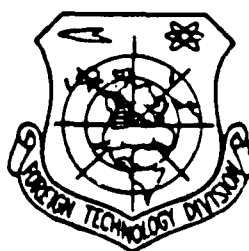
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EVALUATION OF THE QUALITY OF ATOMIZATION, OBTAINED DURING THE  
ULTRASONIC DISPERSION OF LIQUIDS AND MELTS

by

V.F. Popov



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FTD-ID(RS)T-0672-88

25 October 1988

MICROFICHE NR: FTD-88-C-000877

EVALUATION OF THE QUALITY OF ATOMIZATION, OBTAINED DURING  
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By: V.F. Popov

English pages: 14

Source: Khimicheskaya Promyshlennost', Nr. 12,  
December, 1964, pp. 18-21

Country of origin: USSR

This document is a machine translation.

Input by: David Servis, Inc.

F33657-87-D-0096

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А а	<i>А а</i>	A, a	Р р	<i>Р р</i>	R, r
Б б	<i>Б б</i>	B, b	С с	<i>С с</i>	S, s
В в	<i>В в</i>	V, v	Т т	<i>Т т</i>	T, t
Г г	<i>Г г</i>	G, g	У у	<i>У у</i>	U, u
Д д	<i>Д д</i>	D, d	Ф ф	<i>Ф ф</i>	F, f
Е е	<i>Е е</i>	Ye, ye; E, e*	Х х	<i>Х х</i>	Kh, kh
Ж ж	<i>Ж ж</i>	Zh, zh	Ц ц	<i>Ц ц</i>	Ts, ts
З з	<i>З з</i>	Z, z	Ч ч	<i>Ч ч</i>	Ch, ch
И и	<i>И и</i>	I, i	Ш ш	<i>Ш ш</i>	Sh, sh
Й й	<i>Й й</i>	Y, y	Щ щ	<i>Щ щ</i>	Shch, shch
К к	<i>К к</i>	K, k	Ъ ъ	<i>Ъ ъ</i>	"
Л л	<i>Л л</i>	L, l	Ы ы	<i>Ы ы</i>	Y, y
М м	<i>М м</i>	M, m	Ь ь	<i>Ь ь</i>	'
Н н	<i>Н н</i>	N, n	Э э	<i>Э э</i>	E, e
О о	<i>О о</i>	O, o	Ю ю	<i>Ю ю</i>	Yu, yu
П п	<i>П п</i>	P, p	Я я	<i>Я я</i>	Ya, ya

\*ye initially, after vowels, and after Ъ, Ы; e elsewhere.  
When written as ё in Russian, transliterate as yё or ë.

## RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	$\operatorname{sech}^{-1}$
cosec	csc	csch	csch	arc csch	$\operatorname{csch}^{-1}$

### Russian English

rot curl  
lg log

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Page 18.

# EVALUATION OF THE QUALITY OF ATOMIZATION, OBTAINED DURING THE ULTRASONIC DISPERSION OF LIQUIDS AND MELTS.

V. F. Popov.

Earlier was derived formula for determining average/mean  
volume-surface diameter of drop in ultrasonic atomization

$$\bar{d}_{s,v} = \frac{0.252}{A} \sqrt[3]{\frac{3Q}{\pi D^2 \rho g \cos \alpha}} \quad (1)$$

where A - amplitude of oscillations of working surface of injecting  
packing;

Q - fluid flow rate;

$\eta$  - dynamic viscosity of atomized liquid;

$\sigma$  - surface tension on boundary/interface liquid - gas;

D - outer diameter of working section;

$\rho$  - density of liquid;

f - frequency of vibrations of working surface of ;

g - acceleration of gravity;

$\alpha$  - angle between generatrix of surface nozzles and vertical  
line.

Characteristic of atomization with the help of average value of  
drop, convenient for mathematical analysis of effect of different  
factors on dispersion, is insufficient for complete description of  
polydispersed set of drops. In order to determine the efficiency of  
the course of processes, for example by heat- and mass exchange, it is  
necessary to still know the distribution of drops according to the

sizes/dimensions, and sometimes also the maximum/overall diameter of drop in the atomization.

Page 19

It is experimentally established that the form of injecting packing and the width of the spectrum of the ultrasonic oscillations, which participate in the dispersion of fluid film, influence with one and the same acoustic parameters and physical properties of the atomized liquid for the distribution of drops according to the sizes/dimensions to a considerable degree.

Tendency to obtain from ultrasonic atomizers circular flame of atomization led to creation of constructions/designs, whose as working link serves thin-walled oscillating shell  $\pi$ . This shell is the component part of the active half-wave packing and is made usually in the form of cone, hemisphere, cylinder or any combination of such surfaces.

Circular flame of atomization is convenient for practical utilization, since chemical apparatus is made by greater part in the form of cylinder or cone. This flame provides the most favorable conditions for preventing the coagulation of fine/small drops during their flight in the gaseous medium: the mass of drops dispersion in the radial direction immediately is translated into the space with the reduced density of atomization.

Fig. 1 depicts construction/design of ultrasonic atomizer with cylindrical shell. As the engine in this construction/design is used magnetostrictive transducer with 1 types concentrator PMS-15, working at frequency  $\sim 20$  kHz. Hollow cylindrical velocity transformer 2, which passes below into the thin-walled shell, is fastened to the concentrator. Oscillatory system is closed with the cover, in lower part of which is arranged/located film former 3. During the propagation of longitudinal ultrasonic oscillations from magnetostrictive transducer in the thin-walled shell of velocity transformer the intensive bending or radial oscillations both the fundamental frequency and the higher harmonics are excited. The normal operation of such atomizers is accomplished/realized predominantly on the higher harmonics. Liquid (or fusion/melt) on the tangential inlet/introduction enters film former 3, where it is formed/shaped into the ring film. At the outlet from the film former the film falls on the external surface of the vibrating thin-walled shell, where it is peptized in the radial direction, forming the circular flame of atomization (Fig. 2).

In connection with complexity of process of ultrasonic dispersion of thin layers of liquids and fusions/melts to represent previously, as drops in atomization will be distributed according to sizes/dimensions, is impossible; distribution curves for specific conditions can be obtained only by experimental way.

Graphs of distribution of drops in atomization give complete

presentation/concept about picture of atomization, in this case decisive importance for engineering calculations has volumetric characteristic, which shows, as atomizer "processes" fluid film. The volumetric distribution curve can be used also for calculating any average/mean characteristics, but it is preliminarily desirable to smooth out the inaccuracies of the form of curve, caused by the insufficient number of measurements. In connection with the fact that the number of measured drops in the atomization is usually limited, the statistical fluctuations are sometimes very noticeable. Since the direct levelling of the differential distribution curve can lead to the errors, are more expedient experimental data to represent in the form of integral distribution curve. If necessary, using the obtained integral curve, it is possible with the help of the known procedures of graphic differentiation to construct more accurately and differential distribution curve.



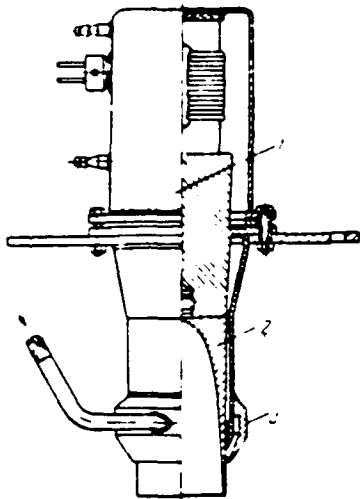


Fig. 1. Ultrasonic atomizer of liquids and fusions/melts: 1 - concentrator; 2 - velocity transformer; 3 - film former.

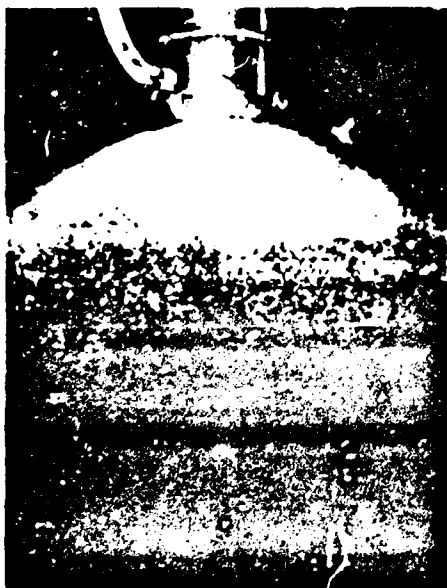


Fig. 2. Circular flame of atomization, formed by ultrasonic atomizer.

Page 20.

For further considerations we will use data of one of experiments. Is pulverized water with  $t=25^{\circ}\text{C}$  by ultrasonic atomizer with the cylindrical shell with a diameter of  $D=0.08\text{ m}$ ;  $A=46\text{ }\mu$ ,  $Q=0.45\text{ m}^3/\text{h}$ ,  $\eta=1\cdot 10^{-3}\text{ kg}/(\text{m}\cdot\text{s})$ ,  $\sigma=0.073\text{ N/m}$ ,  $\rho_{\text{w}}=998\text{ kg/m}^3$ ,  $t=20.5\text{ kHz}$ ,  $\cos\alpha=1$ .

According to formula (1) we will obtain  $\bar{d}_{\text{v},1}=164\text{ }\mu$ . The volumetric distribution curve in the integral form for this test is given for Fig. 3. Along the axis of abscissas on the graph are plotted the diameters of drops  $d_{\text{v}}$ , while along the axis of ordinates - volumetric content of the drops of this class in atomization  $G_{\text{v}}$ .

Graphic plotting of curves of distribution for each specific case presents essential difficulties. Furthermore, to put to use such curves during calculations is very inconvenient. Therefore it would be desirable curve of distribution as the mean diameter of drop in the atomization, to represent in the form of equation with the minimum number of coefficients, which would completely characterize this distribution.

In connection with insufficient study of processes of dispersion of theoretical conclusion/derivation of similar equations there does not exist, although known several empirical formulas, utilized mainly in connection with solid injection of liquids and refinement solids. On the basis of statistical methods for describing the volumetric

distribution of drops in the atomization is obtained the equation

$$\frac{dG}{dy} = \frac{\beta}{\sqrt{\pi}} \exp(-\beta^2 y^2) \quad (2)$$

where G - the volume fraction of drops in the atomization less  $d_i$

y - distribution function;

$\beta$  - coefficient, which characterizes the evenness of dispersion.

In this equation diameter of drops is taken as equal from 0 to  $\infty$ , that it does not correspond to real change of sizes/dimensions of drops in ultrasonic atomization, in which are distributed drops of specific minimum and maximum size.

Expression

$$y = \ln \frac{ad}{d_m - d} \quad (3)$$

where a - parameter of distribution, is most satisfactory function, which considers real limits of change of diameter of drops in atomization;

d - diameter of drop;

$d_m$  - maximum/overall diameter of drop.

For determining constants  $\beta$  and a it is possible to integrate equation (2) and to solve obtained expression with the help of probability integral. However, from these operations it is possible to be failed, after applying logarithmic-probability grid.

Fig. 4 shows application of logarithmic-probability equation taking into account limits of change of diameter of drops in ultrasonic atomization for experiment in question. On the horizontal axis are deposited/postponed the frequencies of values  $d$  in the atomization according to the probabilistic scale, on the vertical axis - distribution of drops according to the sizes/dimensions. If the diameters of drops in the ultrasonic atomization had normal a distribution along the gaussian curve, the values of the studied sign it would be possible to plot on the axis of ordinates along the evenly divided scale. In this case the straight line would express theoretical normal distribution. But the distribution of drops in the ultrasonic atomization differs from normal, and the graphic representation of this distribution according to the evenly divided scale gives broken line. The more this line differs from straight line, the more the empirical distribution differs from normal. But if the values of the studied sign are set aside according to the logarithmic scale, then any distributions of drops in the atomization, different from the normal, will be evinced by logarithmic-probability coordinate grid by straight line. The values of average values and deviation from them also will be placed on this straight line, which will extremely facilitate the problems of determining the coefficients in equations (2) and (3) and "levelling" of experimental errors.

It is easy to determine parameter  $a$  in equation (3) from equation of straight line, which represents distribution. With  $G=50\%$ , when  $y=0$  and  $d=d_0$ ,

$$a = \frac{d_m - d_0}{d_{50}}$$

Let us designate coordinate on logarithmic scale

$$K = \frac{e}{d_m d}$$

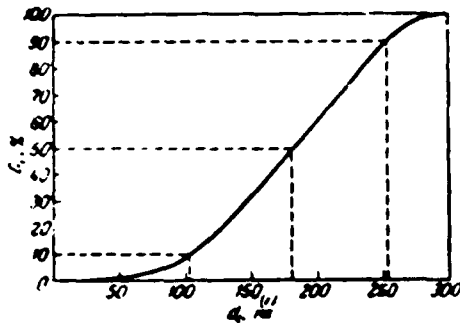


Fig. 3. Curve of volumetric distribution of drops in atomization.

Key: (1).  $\mu$ .

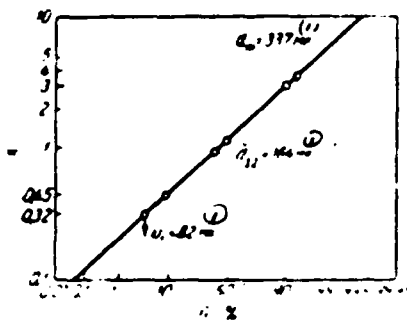


Fig. 4. Curve of volumetric distribution in logarithmic-probability coordinate system.

Key: (1).  $\mu$ .

Page 21.

Then parameter  $\beta$  is determined by inclination/slope of line, which represents distribution, and it means by any two points on it. The greater  $\beta$  all the more evenly dispersion.

Maximum size of drop in atomization can be determined by

trial-and-error method with drawing of dependence between K and G. It is usually sufficiently two-three selections of values  $d_m$ . However in order to obtain a good approximation/approach to actual value  $d_m$ , it is necessary on the integral distribution curve to preliminarily determine values of 10-, 50- and 90% of volume ( $d_{10}$ ,  $d_{50}$  and  $d_{90}$ ).

For our test these values we find for Fig. 3:  $d_{10}=103 \mu$ ,  $d_{50}=180 \mu$ ,  $d_{90}=253 \mu$ . At the logarithmic-probability coordinate system these values lie/rest on straight line (see Fig. 4).

From Fig. 4 we have

$$\frac{K_{90}}{K_{10}} = \frac{K_{50}}{K_{10}}$$

or

$$K_{50}^2 = K_{90}K_{10}$$

Supplying latter/last equation appropriate values of K, we find

$$\frac{d_{50}^2}{(d_m - d_{10})^2} = \frac{d_{90}}{d_m - d_{90}} \cdot \frac{d_{10}}{d_m - d_{10}}$$

whence

$$\frac{d_m}{d_{10}} = \frac{d_{90}(d_{90} + d_{10}) - 2d_{50}d_{10}}{d_{50}^2 - d_{90}d_{10}} \quad (4)$$

After substitution into equation (4) of numerical values  $d_{10}$ ,  $d_{50}$ ,

and  $d_{..}$  for experiment in question let us find maximum size of drop in atomization  $d_m=337 \mu$ .

For determining parameter  $\beta$  it is possible to use, for example, two points on straight line:  $k_{..}$  and  $K_{..}$ , that correspond to 50- and 90% volumes. In this case

$$\beta = \frac{0.394}{\lg \left( \frac{K_{90}}{K_{50}} \right)} \quad (5)$$

For our case

$$K_{90} = \frac{253}{337 - 253} = 3.02$$

and

$$K_{50} = \frac{1}{\alpha} = \frac{180}{337 - 180} = 1.145$$

Through equation (5) we find  $\beta=0.9$ .

It should be noted that value  $\beta$  under varied conditions for ultrasonic atomization vary within the range of 0.8 to 1.2. The average/mean volume-surface diameter of drop in the atomization can be determined according to the equation

$$\bar{d}_{v,s} = \frac{d_m}{1 + \alpha \cdot 10^{\beta}} \quad (6)$$



We find

$$\bar{d}_{s,1} = \frac{337}{1 + 0,782 \cdot 2,73^{0,5} \cdot 0,54} = 163,5$$

Key: (1).  $\mu$ .

Thus, values of average/mean volume-surface diameter of drops, calculated according to equations (1) and (6), virtually coincide.

Sometimes it is necessary, besides average values in this distribution, to find deviations from them. From the straight line of volumetric distribution easily they can be found, for example, volumetric last drops by size/dimension less  $\frac{2,1}{2} = 82 \mu$  and more than  $2\bar{d}_{s,1} = 328 \mu$ . The corresponding values  $K$  in this case are equal to

$$K_1 = \frac{82}{337 - 82} = 0,32$$

and

$$K_2 = \frac{328}{337 - 328} = 36,4$$

After plotting value of  $K_1$  on axis of ordinates and after leading then horizontal line to intersection with straight line of distribution, on axis of abscissas let us find appropriate volume fraction of drops  $v_1 = 6.3\%$ . Consequently, in obtained dispersed system 6.3% by volume falls to the share of drops size/dimension less  $\frac{2,1}{2}$ .

Value  $K_2$  exceeds the limits of graph, and value on axis of

abscissas corresponding to it comprises one hundredths of a percent. Hence it follows that drops with the size/dimension of more than  $2\bar{d}_{11}$  in the dispersal system it is negligibly small.

For construction by straight line, which represents in logarithmic-probability coordinate system volumetric distribution of drops in atomization, is sufficient to know any two values, for example  $d_{11}$  and  $\beta$ . Average/mean volume-surface diameter can be calculated previously according to equation (1), and coefficient  $\beta$  is accepted equal to 0.8-1.2. Putting to use the constructed straight line of distribution, we produce the preliminary evaluation of all required parameters for the engineering calculation.

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